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A Comparison of Bee Abundance and Species Richness in Three Managed Grassland Types

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A COMPARISON OF BEE ABUNDANCE AND SPECIES RICHNESS IN THREE MANAGED GRASSLAND TYPES

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ABSTRACT

Bees are threatened by environmental changes, pathogens, and pesticides (Pettis, 2012, Meeus et al., 2018). The goal of the study is to compare and evaluate the bee abundance and species richness in three different field types. My hypothesis is that bees would favor the fields planted for their benefit, and that the tall grass dominated plantings would be preferred over mowed fescue. My findings have low power considering few replicates and the use of relative abundance and relative species richness for statistical analyses. Bee abundance and species richness had an overall positive relationship of varying degrees across habitat types. Relative bee abundance was statistically different when all three habitats were tested and when the tall grass and pollinator plots were tested. There was no significant difference between relative bee abundance in fescue and tall grass fields, but bees were collected at a higher abundance in fescue fields than in the tall grass. I suggest that the NRCS continues to advocate for pollinator plantings in future conservation plantings in order to promote visitation of pollinators, especially bees. My intention is that these findings create a base for comparison with future sampling of bee populations on the Green River Preserve.

Key words: Bee, Pollinators, Tall Grass, Fescue, Pollinator Plantings

This work is dedicated to my parents, Gina and Bob Russ, my grandmother, Granberry, and our pug, Chigger. Without them, I would not be where I am today.

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INTRODUCTION

An overview of bees

Bees provide pollinator services essential to the success of wild plants and important crops (Sutter et al. 2017). Animal pollinators provide one-third of the pollination services to crops globally (Petersen and Nault, 2014, Winfree et al., 2009). Bees are the most important pollinating insects because they exhibit flower constancy, meaning that a bee will return to the same species of plants over multiple foraging trips (Shrader et al., 2016). Bees actively gather pollen and incidentally transfer pollen to up to hundreds of flowers in one trip (Shrader et al., 2016). People rely on insect pollination for 90 different crops in the United States (Batra, 1984). European honey bees, *Apis mellifera* L., are the primary managed species for crop pollination in the United States (Aslan et al., 2016). Wild bees, including ground-nesting bees, have been observed as pollinators for crops as well. (Horth et al., 2018, Tepedino, 1979). Bumblebees provide 10% of agriculture pollination services (Crowther, 2019). Unfortunately, bee populations are in decline worldwide. Evidence of bee decline is thought to be due to numerous factors that include habitat loss, pathogens, pesticides, and climate change (Koh et al., 2015, Meeus et al., 2018). Identifying and tracking bee populations is a crucial step to conserve these important creatures. Researchers and other concerned groups, primarily the Natural Resources Conservation Service (NRCS) work to restore sites that have low levels of pollinator favoring plants in efforts to increase bee visitation.

Knowing the needs of bees is important in understanding what draws them to a particular area. Pollinators' three basic habitat needs are foraging plants, nesting sites, and protection/shelter (Shrader et al., 2016). Specific foraging periods vary across bee species and can affect bee visitation (Mallinger et al, 2016). Bees require access to pollen and nectar sources from early spring to late fall. Bees differ in their foraging abilities depending on their body size and needs. Larger bees can carry pollen longer distances than small bodied bees (Wright et al., 2015).

Bees are categorized into two groups by their diet: polylectic (generalist) and oligolectic (specialized). An individual of a generalist pollinator species can visit a variety of host plants for needed resources while a pollen specialist may only collect pollen from one or a few plant species. Generalists are more resistant to change in habitat diversity (Leonhardt & Blüthgen, 2012, Tepedino, 1979). Fowler and Droege (2020) have estimated that about 25% of the ~770 species of bees in the Eastern United States are pollen specialists. Both pollen specialists and generalists are essential to pollinate a wide variety of plantings.

Bees are also categorized into ranges of sociality groups: solitary, parasocial, and eusocial. It is estimated that at least 85% of bee species are solitary (Batra, 1984). Solitary bees nest alone but will sometimes aggregate in groups and only closely interact with other bees during mating season. Different species of solitary bees have different shelter habitats. Most solitary bees reside and brood in underground tunnels which results in some altering of soil and landscapes. Mason and leafcutter bees create nests out of natural materials in existing above-ground holes. Carpenter bees drill holes directly in wood. Bumblebees nest in small cavities, reside in abandoned rodent nests or live-in rocks or trees (Lanterman et al., 2019). Eusocial bee species live communally, participate in shared brood care, have a non-reproductive caste, divide labor among individuals, and exhibit overlapping generations (Gibbs, 2012). Parasocial species have individuals with shared nests and lack one or more of the eusocial characteristics. Solitary, parasocial and eusocial bees play different yet important roles in the Earth's ecosystems. Eusocial bees are responsible of some of the largest pollination events for crops. *Apis mellifera* L., is a supergeneralist species that was brought to the United States in order to maintain agricultural production (Aslan et al., 2016). Wild bees that are primarily solitary, aid in crop pollination and also pollinate native plantings.

Grass as a management tool

Grasslands are some of the most threatened terrestrial ecosystems and they account for 64% of Kentucky's rare communities listed by the Nature Conservancy (Barnes, 2004). The Great Barrens of Kentucky are managed as grasslands with forbs and shrubs (Baskin et al., 1994). Conservation services under the United States Department of Agriculture (USDA) that provide guidance for grass plantings include the Natural Resource Conservation Service (NRCS), Conservation Reserve Program (CRP) and Conservation Reserve Enhancement Program (CREP). Evaluation of conservation efforts that support pollinator diversity is crucial in the continuation of programs such as CRP.

Indian grass (*Sorghastrum nutans* (L.) R. C. Nash) and Big Blue Stem (*Andropogon gerardii* Vitman) are the primary grasses of the mesic grasslands of the central plains of North America and the tallgrass sites on the Green River Preserve- where we completed our samples. *S. nutans* and *A. gerardii* are commonly referred to as co-dominant species, but their cover change patterns and response to environmental changes are different (Silletti and Knapp, 2002). *A. gerardii* was exhibited in decline within 15 years resulting in an ecosystem change in composition (Silletti and Knapp, 2002). It is important to know projected changes in habitat structure that can directly affect the function.

Habitat restoration is a primary method to help restore native bee populations (Harmon-Threatt, 2016, Hopwood, 2008). Planting tall grass is an effective management practice that affects bee visitation (Buckles, 2019). Proper maintenance (e.g., burning) after initial management is crucial for the sustainability of plant diversity in a habitat (Harmon-Threatt, 2016). Tonietto et al. (2017) found that restored tall grass prairies can support bee communities similar to those in remnant prairie habitats. Other benefits of grass plantings include that of reduced erosion, improved water quality, and reduced leaching of nutrients.

Threats to bee diversity in landscapes

Habitat loss due to human disturbance is regarded as the leading cause of pollinator decline (Winfree et al., 2009). A habitat for pollinating individuals contains the essential resources and suitable nesting sites (Klein et al., 2007). Causes of habitat loss include herbicide use (Pettis et al., 2012) and fragmentation of plant communities (Yian et al., 2016) caused by agricultural practices and deforestation. Bees are central-place foragers, therefore, breaks in habitat are extremely disruptive and cause decreases in pollinator diversity and population size (Persson et al., 2018, Wright et al., 2015, Yian et al., 2016). Bees complete cycles of gathering resources and returning to their nest during their foraging time (Bell, 1990).

Solitary bees are more affected by modern agriculture than eusocial bees. Solitary bees cannot handle the pollination of one massive event on a monoculture crop and are left without resources after the brief pollination time (Batra, 1984). Irrigation can also cause damage to the brood through increased soil moisture that promotes fungal growth. It is most crucial for pollinator species to have constant floral availability, especially during the queens' nest-founding stage (Lanterman et al., 2019).

Hypotheses

The goal of this study is to determine whether bee species diversity and relative abundance differs across three different human-managed habitats. The three habitats are pollinator dominated plantings, mowed fescue fields, and tall grass. In the experiment, I used bee bowls and spot netting to sample bee populations in three replicated, human-managed, grass-dominated habitats on the Green River Preserve (GRP). My a *priori* hypothesis was that bees would be found at the highest relative abundance, family abundance and diversity in the pollinator plantings, followed by tall grass dominated fields, and then mowed fescue fields. The null hypothesis was that there would be no statistical significance between the habitats for bee abundance and species richness.

METHODS

Site description

The study took place on the Western Kentucky University's Green River Preserve (GRP), located in Hart County, Kentucky (McGrain and Currens 1978, Woods et al., 2002). The GRP occupies two regions known as the Crawford- Mammoth Cave Uplands and Western Pennyroyal Karst Plain (McGrain and Currens 1978, Woods et al., 2002).

Tall grass: The preservation of the tall grass prairie is needed to control erosion run-off to the Green River, and in turn, improve the quality of wildlife. The tall grass plantings are currently dominated by Indian grass (*Sorghastrum nutans* (L.) Nash) accompanied by big bluestem (*Andropogon gerardii* Vitman). The CP2 mix and CP25 mix were selected to meet the requirements of the Conservation Reserve Enhancement Program (CREP) and Conservation Reserve Program (CRP) by Clark (2005) with intentions of establishing small mammal habitats. These mixes include a total of 10 native plant species listed in Jestin Clark's (a former WKU graduate student) thesis. These plantings include *Schizachyrium scoparium* (Michx.) Nash, *Cassia fasciculata* Michx., *Desmanthus illinoensis* (Michx.) MacMill., *Rudbeckia hirta* L., *Echinacea purpurea* (L.) Moench, *Ratibida pinnata* Barnhart, *Dalea purpurea* (Rydb.) Barneby, and *Dalea candida* Willd.

Pollinator plantings: The plantings were created to favor pollinators by having a mix of species used by bees and other flower visitors during their active period. The plantings have been burned in the past as a management practice. The mixes of the pollinator plantings are listed in the following table. Active blooms were different across the pollinator plots depending on collection date and site.

Table 1. Pollinator Planting Species

Pollinator plantings
Agalinis tenuifolia (Vahl) Raf.
Asclepias tuberosa L.
Chamaecrista fasciculata (Michx.) Greene
Cichorium intybus L.
Cirsium discolor (Muhl. ex Willd) Spreng
Conoclinium coelestinum (L.) DC.
Coreopsis lanceolata L.
Coreopsis tinctoria Nutt.
Desmodium paniculatum (L.) DC.
Echinacea purpurea (L.) Moench
Elephantopus carolinianus Raeusch
Lespedeza cuneata G. Don
Monarda fistulosa L.
Passiflora incarnata L.
Rudbeckia hirta L.
Solidago spp. L.
Verbesina alternifolia (L.) Britton ex Kearney
Verbesina virginica L.
Vernonia fasciculata Michx.
Vernonia gigantea (Walter) Trel.

Mowed fescue: The mowed fescue fields formally used for grazing and hay included varieties of fescue grass (*Festuca* spp. L.), grease grass (*Tridens flavus* (L.) Hitchc), and orchard grass (*Dactylis glomerata* L.). In addition, White clover (*Trifolium* *repens* L.) was found scattered throughout the fields. The sites visited in the study were mowed within a month before each collection time.

Other plant species adjacent to the fescue fields sampled include frostweed (*Verbesina virginica* L.*)*, wingstem (*Verbesina alternifolia* (L.) Britton ex Kearney*)*, ironweed (*Vernonia* spp.), goldenrod (*Solidago* spp. L.), and blackberry (*Rubus* spp. L.).

Bee collection protocol

I used the guidelines in the Very Handy Manual by Sam Droege (2010) to complete the sampling. I used the bee bowl method in single 30 meter transects to collect a sample of bee specimens. Bee bowls, also called pan traps, are meant to mimic flowers with their colors and attract bees. This type of trapping is easy to use and allows for a

Figure 1. Jack Mayo and I set up a transect in a fescue field (taken September 6, 2019)

longer sampling time as long as the soapy water solution remains in the bowls. The bee bowls were purchased from New-Horizon bee bowl services in three different colors: white, yellow, and blue. Using three different colors benefits the overall population representation (Sircom et al., 2018). Bowls were placed in one-meter intervals on straight transects and alternated colors (white, yellow, blue…). A total of 30 bowls were used for each 30-meter transect (10 bowls of each color). Bowls were not placed in a perfect line, and instead were positioned slightly askew to transects in order to avoid placing traps directly under the field flags and create a more organic site. Placement of flags varied in samplings from every meter, to every five meters, and only at the beginning and end of the transect. We tamped down the vegetation around the placement of each bowl to ensure visibility of the bowls especially in dense vegetation.

Figure 2. Mowed fescue sample (taken August 30, 2019)

Each bowl about one half full with a soapy water solution (composed of one large squirt of blue dawn dish soap into 3.78 liters of water). The soap acts as a surfactant and results in the bees sinking when touching the surface of the water in the bowls. The three habitats are shown of me filling the bee bowls with the soapy water solution (fig. 2-4).

Figure 3. Tall grass planting sample (taken August 30, 2019)

We selected and sampled three sites of each habitat type on each sampling day for a total of 9 transects and 270 bowls placed on each sampling day. At each transect, the GPS location, elevation, and orientation of transect were recorded, along with the start and end times of collection (Appendix A). The bowls were left in their respective locations for 24 hours for each collection.

Figure 4. Pollinator planting sample (taken August 30, 2019)

Upon collection, bowls were drained of the water-soap solution, and specimens were placed in jars labeled by each location. In addition, the start and end time of each collection was recorded. Upon return to the lab, the bees were removed from the collection jars and immersed them in an approximately 70% ethanol solution in separate labeled containers by site and date.

The spot net method allows for collection of other taxa not represented in the pan traps and sampling is completed in short intervals (Sircom et al., 2018). For spot netting, three replicated sites of each habitat were selected for collection. Some of the fields were the same in the bee bowl locations. Ample space between the spot netting and bee bowls was ensured in order to prevent any disturbance in sampling. Each field was sampled by two individuals, each with a 38.1-centimeter insect net purchased from BioQuip. Primary samplers were Adam Miles and Jack Mayo while I participated in a few collections. We walked in straight transects through the field for 10 minutes and captured bees within collection area. The total area sampled did not exceed $100m^2$. The nets were held at a position ready to swipe and were quickly swept when a bee (or bees) was in proximity of the net. The GPS coordinates of the fields and start time and end time were recorded during samplings (Appendix A). Specimens were placed in containers with a 70% ethanol solution and labeled by location, date, and habitat type at capture. This process was completed two times for each location in one afternoon.

Figure 5. (L to R) Adam Miles and Jack Mayo using nets to collect bees in a pollinator field (taken September 7, 2019)

Bee specimens were removed from the ethanol solution and placed in Whirl-Pak bags and mailed to Sam Droege and his team at the USGS bee lab for identification. Each specimen was identified, assigned an ID number, and input into the DiscoverLife database by Erick Hernandez (Anonymous A).

Three bee bowl sample days and two spot netting sample days are included in the analysis. Sampling days were chosen based on the availability of participants and anticipated generally sunny weather. Bees were collected in three different tall grass sites, three different fescue sites, and four pollinator sites. On August 30, 2019, the third pollinator bowl transect was only left out for 7.5 hours due to anticipated rain instead of the full 24 hours. On September 6, 2019, one plot of each treatment was chosen to act as a comparison between the pollinator field that was not measured for the full 24 hours. These data were still used in comparison because relative analyses were used and the bowls were set at peak hours of bee collection. On September 7, we only sampled two fescue and tall grass plantings by spot net because only two bees were captured in each of those habitats that day,

Table 2. Locations of each sampling by date and plot type

Date	21 June, 2019	30 August, 2019	31 August, 2019	6 September, 2019	7 September, 2019
Collection Type	Bowl	Bowl	Net	Bowl	Net
Tall grass	37.2372° N -85.9955° W	37.2369° N -85.9928° W	37.2383° N -85.9958° W	37.2400° N -85.9911°W	37.2380° N -85.9936° W
	37.2402° N -85.9908° W	37.2408° N -85.9933° W	37.2400° N -85.9908° W		37.2380° N -85.9933° W
	37.2419° N -85.9936° W	37.2411° N -85.9908° W	37.2403° N -85.9936° W		
Fescue	37.2386° N -85.9930° W	37.2380° N -85.9933° W	37.2419° N -85.9936° W	37.2419° N -85.9914° W	37.2386° N -85.993° W
	37.2419°N -85.9914° W	37.2419° N -85.9911° W	37.2414° N -85.9914° W		37.2419° N -85.9911° W
	37.2428° N -85.9925° W	37.243° N -85.9925° W	37.2422° N -85.9930° W		
Pollinator	37.2447° N -86.0089° W	37.2380°N -85.9933° W	37.2444° N -86.0089° W	37.2444° N -86.0092° W	37.2428° N -85.9953° W
	37.2380° N -85.9936° W	37.2433° N -85.9953° W	37.2419° N -85.9936° W		37.2411° N -85.9900° W
	37.2419° N -85.9936° W	37.2447° N -86.0089° W	37.2428° N -85.9928° W		37.2380° N -85.9936° W

Statistical methods

I used the alpha level of 0.05 for testing all my hypotheses. I combined some species names such as the names *Halictus ligatus/poeyi* and *Halictus poeyi/ligatus*. The specimens were not specified to a species level due to difficulty in differentiating the two taxa. Three bees were not reported with a species level identification, and they were counted in separate names at the genus level: Two *Lasioglossum* spp. Curtis and one *Melissodes* spp. Latreille found in the pollinator plots.

I, first, checked for normality, homoscedasticity, linearity, and multicollinearity using Statistical Program for the Social Sciences (SPSS™) before validating the linear regressions (IBM, 2019). There were no drastic deviations to the normality line (outliers) detected. The points on the scatterplots of residuals were scattered. Using the variance inflation factor (VIF) value given, I confirmed multicollinearity at 1.0 for all three habitat types meaning there is no correlation between the predictor variables. Because the preliminary tests did not indicate any problems, I proceeded to run the linear regressions.

I ran simple linear regressions for every habitat by bee bowl bee abundance and species richness to find the relationship of the two variables on SPSS™. I also ran a linear regression for bee abundance and species richness for pollinators collected by spot nets because there were ample sample data. There were not enough data from the tall grass and fescue planting's spot net samplings to complete a linear regression. Only five samples of the tall grass bee bowls contained bee specimens in them -which is the absolute minimum number of samples to complete the regression in order to have some power. The greatest number of samples was seven, which was still a relatively small sample size. SPSS reported R^2 values, P-values, and contingency values including slope.

On VassarStats, I used the Fisher's exact test to test for the relative, or "greatest" bee abundance, species richness, and family abundance across the three habitats (Lowry). I did this by ranking bee abundance, species richness, and family abundance, across the three habitats by day of collection. A rank of 1 meant that the bee abundance was highest in that particular habitat, followed by 2, the next most abundant, and lastly, 3, the least abundant. In the event that ranks were tied for "least abundant," they were both assigned 2's. In the event that ranks were tied for "most abundant," they were both assigned 1's. I then took counts of ranks in each habitat to input the Fisher's exact test for analysis. This test allowed me to rank all of the samples together: bee bowl and sweep net. The reported values for the 3x3 Fisher's exact tests are the P_B values, which are the two-tailed probabilities of "the observed array of cell frequencies plus the sum of the probabilities of all other cell-frequency arrays that are smaller than the probability of the observed array" (Lowry). I chose this value to report because I wanted to see if any habitat has a higher abundance, not equal and higher.

I first ran 3x3 Fisher's exact tests to see if there is statistical significance across all three habitats for relative bee abundance and relative species richness. I completed this for the combined bee bowl and sweep net data then just for the bee bowl data. I then completed 2x2 Fisher's exact assessments in order to see where there is statistical significance of relative bee abundance and/or species richness across any two habitats. I combined the bee bowl and spot net data in order to complete relative abundance. I also tested just bowl sampling yields. I reported the one-tailed P-value because I am only testing to see that relative bee abundance in one habitat is more than in the other, instead of more or less.

For the last statistical analysis, I looked at bee abundance among families. I ran a 3x3 Fisher's exact for relative abundance in bee families for combined bee bowl and spot net data.

RESULTS

Bee abundance and relative bee abundance analyses

A total of 471 bees across 12 genera, and 37 species (or species groups) were collected and reported in this study. Out of the bees collected, 210 bees were collected by the bee bowl capture and 261 bees were collected by spot netting. The most individuals were collected from the pollinator plots (374 bees), followed by the fescue (64 bees) and lastly the tall grass (33 bees). The highest species richness was exhibited in the pollinator plantings (32 species), followed by the fescue (21 species), and lastly the tall grass (13 species). All species are widespread across the Eastern United States, and many taxa are found nationwide (Anonymous A).

Table 3. Species and number of specimens collected at each habitat type

Species	Tall Grass	Fescue	Pollinator	Total	%
Apis mellifera L.	0	3	9	12	2.6
Augochlorella aurata (Smith)	1	5	32	38	8.1
Augochlorella persimilis (Viereck)	1	1	15	17	3.6
Bombus auricomus (Robertson)	0	0	35	35	7.5
Bombus bimaculatus Cresson	0	0	10	10	2.2
Bombus griseocollis (De Geer)	0	0	48	48	10.2
Bombus impatiens Cresson	0	3	60	63	13.4
Bombus pensylvanicus (De Geer)	0	1	2	3	0.6
Calliopsis andreniformis Smith	2	11	36	49	10.4
Ceratina dupla Say	2	0	2	4	0.8
Ceratina mikmaqi Rehan and Sheffield	1	0	1	2	0.4
Ceratina strenua (Smith)	1	0	1	2	0.4
Halictus confuses (Smith)	0	1	1	2	0.4
Halictus poeyi Lepeletie/*ligatus* Say	0	1	11	12	2.6
Hoplitis pilosifrons (Cresson)	0	0	1	1	0.2
Hylaeus affins/modestus (Smith)/Say	0	0	8	8	1.7
Lasioglossum admirandum (Sandhouse)	0	4	2	6	1.3
Lasioglossum callidum (Sandhouse)	0	2	5	7	1.5
Lasioglossum coriaceum (Smith)	0	1	1	2	0.4
Lasioglossum fattigi (Mitchell)	0	0	2	2	0.4
Lasioglossum hitchensi Gibbs	6	12	35	53	11.4
Lasioglossum imitatum (Smith)	0	2	6	8	1.7
Lasioglossum paradmirandum (Knerer and Atwood)	1	0	0	1	0.2
Lasioglossum spp. Curtis	0	0	2	2	0.4
Lasioglossum tegulare (Robertson)	1	0	1	2	0.4
Lasioglossum trigeminum Gibbs	3	4	4	11	2.4
Lasioglossum versatum (Robertson)	12	6	18	36	7.6
Melissodes bimaculatus (Lepeletier)	1	0	0	1	0.2
Megachile brevis Say	0	1	0	1	0.2
Megachile campanulae (Robertson)	0	1	0	1	0.2
Megachile petulans (Cresson)	0	1	2	3	0.6
Melissodes bimaculatus (Lepeletier)	0	1	0	1	0.2
Melissodes communis Cresson	0	1	2	3	0.6
Melissodes denticulatus Smith	0	0	2	2	0.4
Melissodes spp. Latreille	0	0	1	1	0.2
Melissodes tinctus LaBerge	0	0	2	2	0.4
Xylocopa virginica (L.)	1	2	17	20	4.2
Total bees at each habitat	33	64	374	471	
Percentage catch each habitat	7.0%	13.6%	79.4%		

Total bees collected and percentage catch at each habitat type are included.

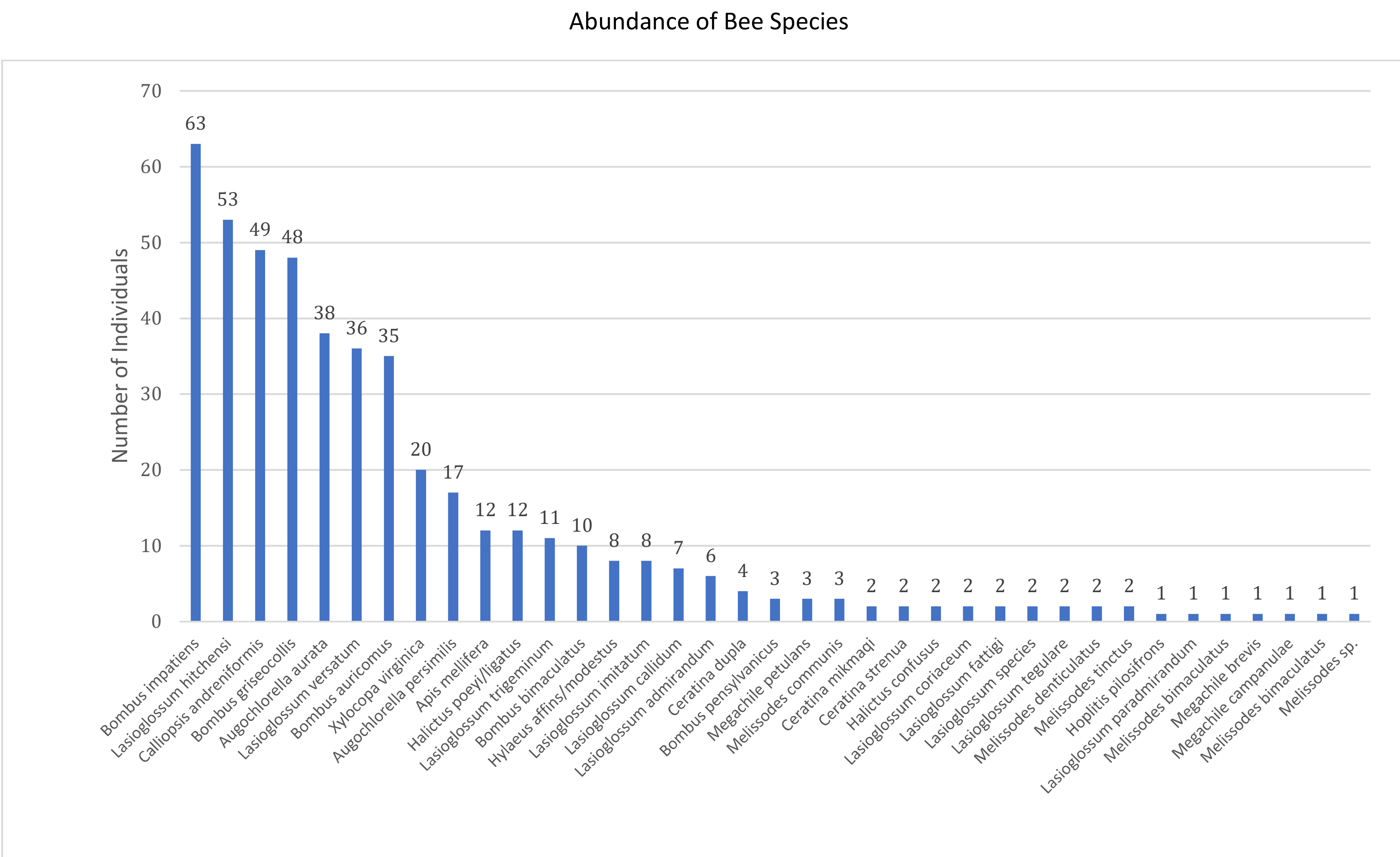

Figure 620. Abundance distribution of the 37 species of bees collected by bee bowls and sweep nets

Linear regressions of bee abundance and species richness

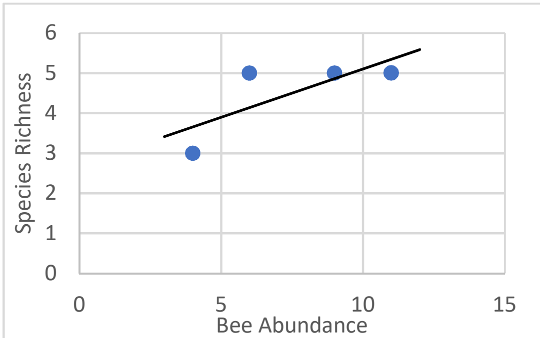

Figure 7. Tall grass linear regression for bee bowls

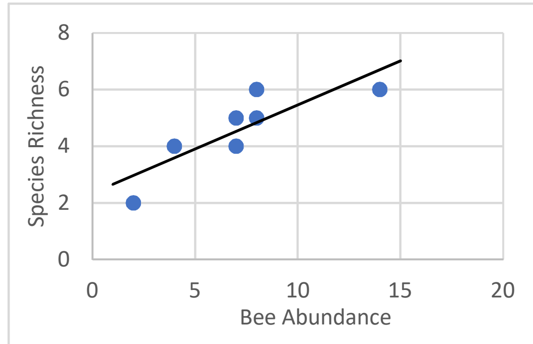

Figure 8. Fescue linear regression for bee bowls

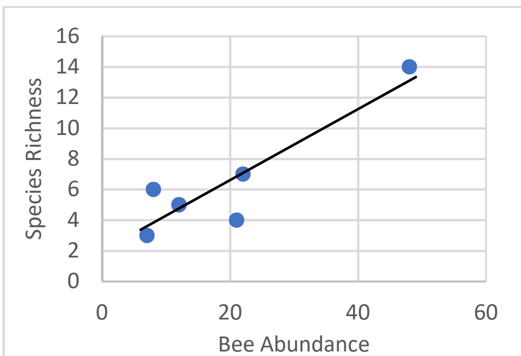

Figure 9. Pollinator plantings linear regression for bee bowls

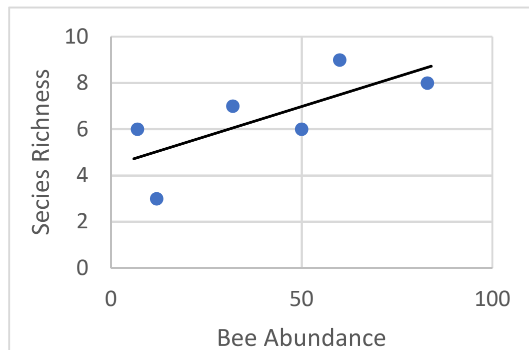

Figure 10. Pollinator plantings linear regression for spot netting

Table 4. Results of linear regressions for each habitat and indicated sampling type

Group	df	p	F	R^2	Slope
Tall Grass Bee Bowl	2	0.250	2.579	0.563	0.241
Fescue Bee Bowl	5	0.018	11.816	0.703	0.311
Pollinator Bee Bowl	5	0.005	23.203	0.823	0.232
Pollinator Spot Net	4	0.103	4.261	0.526	0.051

Relative bee abundance across habitats

The Fisher's exact test evaluated counts of ranked abundance for each individual sampling day.

Table 5. P- values from Fisher's Exact tests of ranked abundance by habitat type

Habitat Types and Sample Methods	P_B value	One-tailed P-value
All Habitats, Net and Bowl	0.038	
All Habitats, Bowl	0.18	
Pollinator and Tall Grass, Net and Bowl		0.0039
Tall Grass and Fescue, Net and Bowl		0.26
Pollinator and Fescue, Net and Bowl		0.499
Tall Grass and Fescue, bowl		0.199
Tall Grass and Pollinator, bowl		0.05
Pollinator and Fescue, bowl		0.499

Relative species richness across habitats

Fisher's exact test showed counts of ranked abundance for each individual sampling day.

Table 6. P-values from Fisher's Exact tests of ranked species richness by habitat type

Habitat Types and Sample Methods	P_B value	One-tailed P-value
All Habitats, Net and Bowl	0.007	
All Habitats, Bowl	0.476	
Pollinator and Tall Grass, Net and Bowl		0.1
Tall Grass and Fescue, Net and Bowl		0.4
Pollinator and Fescue, Net and Bowl		0.1
Tall Grass and Fescue, bowl		0.19
Tall Grass and Pollinator, bowl		0.49
Pollinator and Fescue, bowl		0.49

Family abundance analysis

I, then, tested family abundance across the three habitats and all the samplings. The resulting P_B value was 0.004 indicating relative bee abundance of families was significantly different across all of the samplings and habitats.

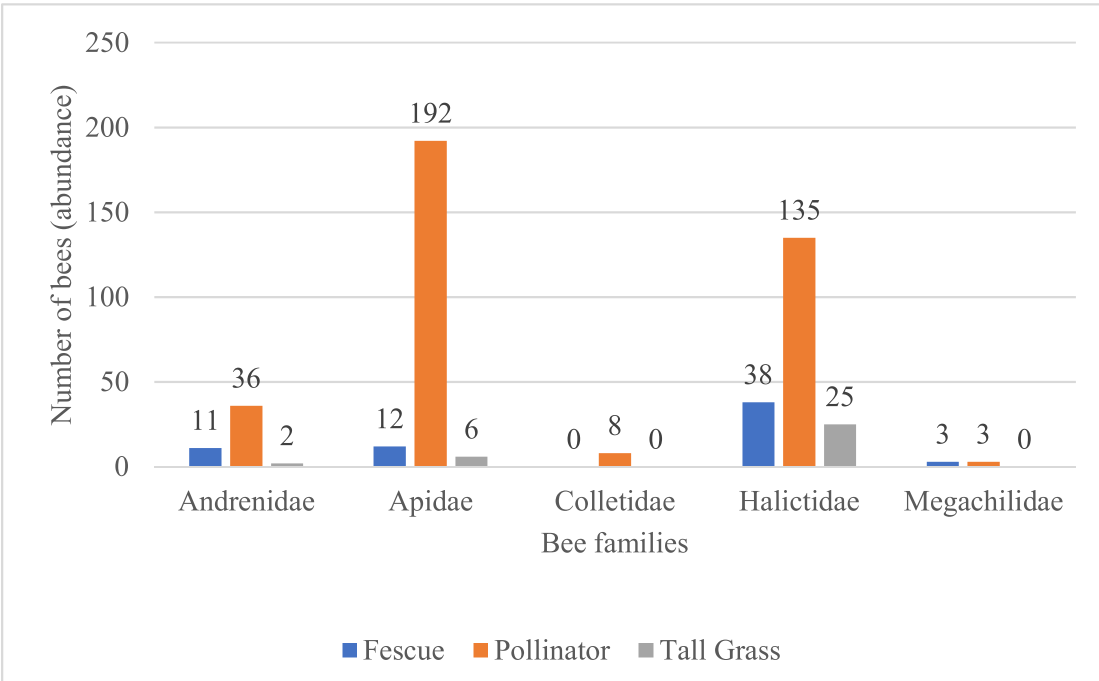

Figure 11. Bee abundance by family in each habitat type. It includes combined abundance from both sampling methods

DISCUSSION

This study aimed to compare the abundance and species richness of bees in three different managed grassland habitats on the Green River Preserve. Baseline species inventory was also a goal but was limited by the small sample size. Three bee bowls and two spot net samplings showed there was an overall trend of greatest abundance and species richness in the pollinator plantings (374 bees and 33 species), second greatest abundance and species richness in the mowed fescue (64 bees and 21 species), and the lowest abundance and species richness in the tall grass plantings (33 bees and 13 species). As expected, the pollinator plantings are the superior habitat type for bee abundance and species richness compared to mowed fescue and tall grass. Unexpectedly, the tall grass plantings did not contain a significantly higher abundance of bees than the mowed fescue.

There was an exhibited difference in relative bee abundance in tall grass and pollinator plots. There was no difference in relative abundance in any other individual habitat comparisons. This leads me to one conclusion: that tall grass alone may not be as effective a conservation tool for bees as we thought. Sutter et al. (2017) say that it is not primarily the diversity of plantings that attracts the highest abundance of pollinators, but easy accessibility of resources for each individual’s needs. The best habitats for bees contain plantings for season-long blooms to constantly provide pollen sources for the bees (Williams et al., 2015). Important relationships observed are between key plant species (pollen sources) and bee target group (pollinators) visitation (Sutter et al., 2017).

Future samplings of bees should include more in-depth information on pollen sources and pollinator visitors to investigate the relationship between the two.

The most abundant species collected in each habitat was different. Different bees' characteristics such as bee size affect capture rate by each collection method. Some taxa are easier to see when spot netting and some taxa can climb out of bee bowl traps. The species *Bombus impatiens* Cresson was the most abundant (60 individuals) in the pollinator plantings and were all obtained by spot netting. Bumblebees (*Bombus* spp. Latreille) are highly abundant when found and are highly important pollinators (Lanterman et al., 2019). The queens of *Bombus impatiens* establish their eusocial nests in spring and workers can forage and carry pollen long distances throughout the active season. It is not surprising that *Bombus* individuals were found at a high abundance in the pollinator plantings.

With a total of 12 individuals, *Lasioglossum versatum* (Robertson), was the most abundant species collected in the tall grass. *L. versatum* is a widespread sweat bee in Eastern North America (Michener, 1966). *L. versatum* was collected in all three habitat types (6 in fescue fields and 18 in pollinator plantings). Many *Lasioglossum sp.* Curtis are communal nesters, so it is expected to see many at once. They like nesting in areas exposed to the sun on sparse vegetation growing on hard soil (Michener, 1966). The most abundant species in the fescue fields is *Lasioglossum imitatum* (Smith), another common sweat bee. *Lasioglossum* is the most abundant and habitat diverse genus of bees (Danforth et al., 2003). It is not surprising that these individuals were collected at high abundance during our sampling across all of the habitat types. There is a pervasive theme of common generalist species on the preserve.

Certain species of bees were found exclusively in each habitat. *Lasioglossum paradmirandum* (Knerer and Atwood) was only found in the tall grass. *L. paradmirandum* is recorded as common and found in Eastern North America (Anonymous A). The species *Megachile brevis* Say and *Megachile campanulae* (Robertson) were solely found in the fescue plantings. *M. brevis* is a common species found across North America and *M. capanulae,* the bellflower resin bee is found in Eastern North America (MacIvor and Moore, 2013). A total of 10 different bee species/species groups were found exclusively in the pollinator plantings (table 2). According to anonymous A, these species are primarily found in North America at varying ranges.

Out of all the individuals collected, the sweat bee, *Lasioglossum fattigi* (Mitchell) was the only species stated as uncommon (Anonymous A). *Apis mellifera* L. (European honey bee), a non-wild bee (invasive), is found worldwide and found in relatively low abundance in this study. European honey bees are managed pollinators that are heavily relied on for the success of crop production in the United States (Shrader et al., 2016). Widespread pollination by wild bees is possible, as seen on the GRP. Diversity of wild bee species is essential for the success of pollination of native plants. Each taxon has unique requirements in resources and habitat to thrive in a particular area. For example, *Andrena* spp. Fabricius (genera of mining bees) require early spring bloom and nesting space, while Halicitae (family of sweat bees) and *Bombus* spp. require floral blooms throughout the remainder of the summer (Mallinger et al., 2016). This is further supported by the significant difference in family abundance across the three habitats.

The only significant difference in species richness was exhibited when all habitats and sampling methods were evaluated together. A reason for these results is that one sampling had a tie for relative species richness in the tall grass and fescue samplings for the most species above the pollinator species richness. The small sample size limited data analysis to be completed for relative abundance in ranks which is a less powerful test than abundance. Species of bees were found at varying counts across the habitats, but not always at a significant difference (Table 2). Arathi's (2019) study found different bee genera in Conservation Reserve Program (CRP) and CRP pollinator habitat fields, and not at a significant difference. Bee species were found in CRP pollinator enhanced fields that were absent in the regular CRP fields. This further supports the claim that bee visitation is dependent on many factors. Significant differences in bee abundance are not always observed, but differences in bee population are present across differently treated habitats.

Grazing and hay management, exhibited in the GRP fescue fields in the past, decreases bee nesting ability and behavior (Buckles, 2019). Practices such as these affect current and future populations of bees. Loss of floral resources is one of the leading causes of bee decline (Sutter et al., 2017). Bees are essential for the successful reproduction of most species of flowering plants and are the most important of the insect pollinators (Tepedino, 1979). Bee abundance is highly variable across space and time and is difficult to predict (Choate et al., 2018, Auerbach et al., 2019). Abundance of bees can be vastly different from one week to the next. There are many factors to a habitat that could affect bee abundance that was not investigated including planting composition and weather over the sampling periods.

One shortcoming of this study is its short duration. As a result, a small number of samples were collected which limited the type of data analyses that could be completed. There was consistent habitat type sampling, yet a lack of consistency of sampling across sampling sites. We did not follow the typical sweep netting protocol that is in transects and rather stayed within a particular habitat to collect as many bees as possible. Lastly, there is an outlier in the pollinator planting bee bowl capture linear regression could have swayed the results (figure 9).

Much is still not known of wild bees, their behavior, and their needs. Our study shows areas in which future studies may improve in learning more about bee communities. Analyses of bee populations in habitats that have undergone different management practices are important to complete to create the best future pollinator communities. Records of active blooms during bee collection would be extremely important in finding plant-pollinator relationships. Other data that would be important to gather in future studies include locations of bee nesting sites. The evenness of sampling sites could allow for the evaluation of site-specific comparisons and more accurate location-specific inventory.

Management advice for bee conservation

Bees are the most important pollinators on this planet, and they are in decline worldwide. Much is still not known of bee abundance and species richness dynamics across habitats. Interactions of bee species and their habitat are complex and there are many factors still yet to be investigated (Fründ et al., 2013). A consistent sampling of bee populations is important in that the entire bee population trends cannot be investigated in just one season. The standardized practice of sampling bee populations every two weeks by bee bowls and sweep nets (removing an average of 2,862 bees a season) does not affect bee abundance, species richness, or rarefied richness (Gezon et al., 2015).

Suggestions can still be made towards future management practices to favor bees from my discoveries. My findings have shown that pollinator plantings are superior to mowed fescue and tall grass fescue plantings for bee abundance and species richness. Diverse floral availability in large natural areas attracts pollinators in the largest abundance (Aslan et al., 2016). The incorporation of these habitats is the best way to maintain diverse bee populations. Actions to promote native pollinators are crucial to take because pollination is needed for many ecological systems to succeed.

CONCLUSION

Findings like mine in the GRP contribute to a growing data set of bee presence in North America. There is still great uncertainty surrounding the existing bee species abundance and richness, and these data provide baseline data for future studies in this field. There are also varying degrees of support for a positive relationship between bee abundance and species richness. While there was low power in my tests, they supported that pollinator plantings are a greater bee abundance and diversity than tall grass plantings. The density of tall grass plantings may be reconsidered as a conservation planting because of the statistically significant results for the pollinator plantings and tall grass analyses. The goal of conservation is to protect what communities are intact, then restore those that have been previously destroyed. To reach these goals, it is important to continue sampling bees to understand trends in bee abundance and species richness. I hope that this study is a base for future findings and inspire investigation and conservation of bees at this site and elsewhere in the world.

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